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To cite this article: H N B Khalaf *et al* 2019 *J. Phys.: Conf. Ser.* **1353** 012080

Radioactive and non-radioactive aerosol permeability through two types of analytical filters

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Abstract. AFA analytical filter is the most used one of Petryanov filters in health protection and radiometric and analytical measurements. Therefore, the properties of this filter like efficiency and the permeability of the non-radioactive and radioactive aerosol particles are more important for accurate estimation and protection. AFA Petryanov filters (RSP-20 and RMP-20) are the most popular filters in Russia. In this work, an experimental setup has been constructed to estimate the permeability of the non-radioactive and radioactive aerosol particles through these two type of analytical filters. A standard radon chamber (2 m^3), at Ural federal university is used to create radioactive aerosol. Non-radioactive aerosol or ambient aerosol is considered from ambient indoor air. Aerosol diffusion spectrometer (ADS) is used to measure aerosols concentration and number size distribution with range from 1 nm to 10 μm. The activity size distribution is determined with screen diffusion battery and the AIP-2 cascade impactor with range (0.5-20μm). The measurements are repeated before and after filters to study the PFs filters dispersion and permeability for non-radioactive and radioactive aerosols. ADS filter is used to measure the aerosol concentration and number size distribution before and after filters in ambient air with spatial construction. The effect of size modes of the non-radioactive and radioactive aerosols penetrating the filters is studied. At low aerosol concentration, the filters catch all free unattached radon decay products (RDPs) (1-5 nm) and the most collected activity with active median thermodynamic diameter, AMTD, ~ 20 nm. In the radon chamber at high aerosol concentration, the activity of RDPs free unattached fraction nearly removed. The collected activity with AMTD ~ 20-40 nm is more significant.

Introduction

Recently, fiberglass are widely used as the base of the thin-layer filtering materials for ultrafine filter. High-efficiency particulate air filters (HEPA) are these filters containing ultrafine fiber materials. There are filters of micron and submicron polymer fibers obtained by electrospinning (electrostatic polymer solution spraying) for the purposes of fine purification. These filers are produced In Russia and known as Petryanov filters (FPs) [1]. Petryanov, Fuchs, and Rosenblyum over 70 years ago were developed the manufacturing method for these filters [2, 3]. These filters very efficient due to the electrostatic charge on fibers materials. The FPs give the advantage like a valve less, low resistance and high-efficiency respirator “Lepestok” (petal).

AFAs is the widely used aerosol analytical filters. These filters were developed based on PFs materials. There are many kinds of AFA radiometric analytical filters, like AFA-RMA, AFA-RSP,

AFA-RMV, AFA-RMP, AFA-RGP, AFA-VP, AFA-BA and AFA-HP [1]. AFA-RMV, AFA-RMP and AFA-RSP are designed in the form of disks with a surface area of 3, 10, 20 cm^2. They can be used to perform radiometric, chemical, radio spectrometric, radiographic, weight, bacterial, and dispersed analyses. One of the properties that provide using PF filters in different fields is the surface density. For different PFs materials the surface density ranges from 10 to 50 g/m^2. These filters have a greater elasticity and flexibility, while preserving their structure. In particular, these filters are widely used in individual protection devices for the respiratory organs during inhalation. Also, PFs material is the absence of debris or scraps of fibers, which can contaminate the dispersion medium. Individual fibers have the length of hundreds of meters with strength corresponds to that of polymers.

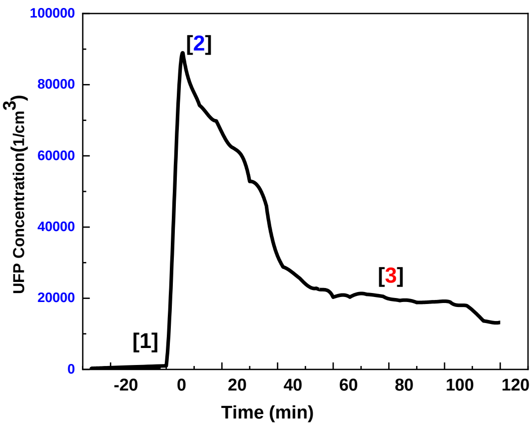
The information about the non-radioactive and radioactive aerosols permeability through filters is an essential properties and directly related to the load during the inhalation of these aerosols. Unlike the dispersion of the aerosol constituent forming the attached fraction is approximately in the micrometre fractions. At the same time, the size distribution of aerosols is much more complex. In applications, a more detailed analysis of the aerosols dispersion distribution is required, mainly in the field of finely dispersed aerosols particles. This is essential for the dosimetry assessments and to correct the interpretation of the measurements results with the aerosols size distributions and concentrations in the air.

In this work, due to the wide usage of Petryanov analytical filters especially in health protection (non-radioactive and radioactive aerosols) an experimental work has been performed to check the permeability of non-radioactive and radioactive aerosols through AFA-RMP-20 and AFA-RSP-20, the widest known Petryanov filters. The characterization of AFA-RSP-20A and FA-RMP-20 analytical filters is described in literature [1–7].

Method

For radioactive aerosols, the experiments were performed out with the 2 m^3 standard radon chamber [8-9]. Additional evaporator generator of aerosol particles are used to inject aerosols into the standard radon chamber to create different radioactive aerosols concentration. Non- radioactive aerosol is taken from the ambient indoor air with limited level of activity. The parameters like number concentration and number size distribution are measured continuously before and during the experiments with aerosol diffusion spectrometer (ADS) in the range from 1 nm to 10 μm [6-7].

Figure 1 (on left graph) presents the aerosols particles concentration variation for the size of ultra-fine particles (UFPs≤ 0.2 μm) with time after the injection of aerosols. In this figure, three points, [1] (The back ground, before aerosol injection) the number concentration of the aerosol, NC= 1k particle/cm^3), [2] (at high aerosol concentration, NC= 100 k particle/cm^3) and [3] (at more stable aerosol concentration, NC= 70 k particle/cm^3).



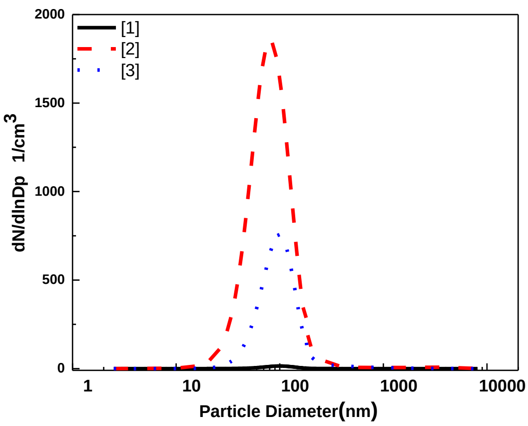


Figure 1. The concentration of ultrafine aerosol particles with time (on left graph) and number size distribution (on right graph) at different aerosol concentrations. 1 (The back ground, before aerosol injection), 2 (high aerosol concentration) and 3 (more stable aerosol concentration).

Figure 1 represents the level of the particle concentration according to the measurement with the ADS instrument in radon chamber. Aerosol concentration during the experiments was in the range from 1.10^3 to 1.10^5 cm^{-3}. The maximum concentration of ultrafine particles (UFP), lower than 200 nm, is approximately 9.10^4 particles/cm^3. The maximum concentration of UFP was reached directly after ending aerosol. Nearly 98% of the aerosol particles are smaller than 0.2 µm (UFPs) as shown in figure 1.

The wide used instrument for thermodynamically measuring particle size ($d_p \leq 0.2$ µm) is a wire screen diffusion battery. In this work, a wire screen diffusion battery with 10 elements has been used to collect and estimate the radioactive aerosol size distribution with range 0.5 to 100 nm [7,10]. The calibration range of the screen diffusion battery d_{50}% from 1.5 to 10.5 nm.

The activity concentration of alpha particles on the PFs filters or wire screens diffusion battery are consequently measured with alpha scintillation radiometer detector; during 30 min after the finishing of the aerosols sampling, each unit is measured for 2 min. The radon equivalent equilibrium concentration (EEC_{Rn}) at the moment of sampling finish is calculated by the modified Kuznets method [10]. The EEC_{Rn} can be estimated by the following equation:

$$EEC_{Rn} = \frac{The\ alpha\ count\ rate}{E_d\ E_F\ F_W K}$$

where E_d is the efficiency of the alpha detector, E_F is the filter or screen efficiency, F_W is the flow rate and K is the Kuznets coefficient. Each screen or filter is measured separately with alpha radiometry detector.

With aerosol diffusion spectrometer (ADS) in indoor air the number size distribution of ambient air is measured before and after filters (figure 2) and the penetration fraction for the two PFs filters RSP-20 and RMP-20 is estimated. The penetration fraction is the ratio between the concentration before and after filter.

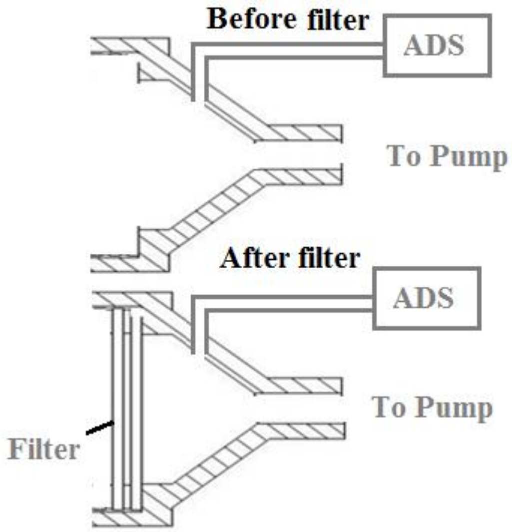


Figure 2. Simple holders for determining filter penetration with ADS.

Results and discussions

The activity size distribution estimated with the wire screen diffusion battery before and after RSP-20 and RMP-20 filters is shown in figure 3. The size distributions are for the low and high aerosol concentrations. Two cases are explained; the first is the direct measurement (before filter) with the wire screen diffusion battery. The second is the measurement with the wire screen diffusion battery while the analytical filter installed before the diffusion battery (after filter) to study the permeability of radioactive aerosol through the analytical filter.

For low aerosol concentration, the size distribution before the filters has a main mode with AMTD ~ 1 nm (70% of activity). The second observed mode with no more 10% of activity has AMTD 20 nm. After filter, when the RSP-20 filter installed, 1 nm is removed completely and about 95% of the collected activity with AMTD ~ 20 nm is stopped by the analytical filter.

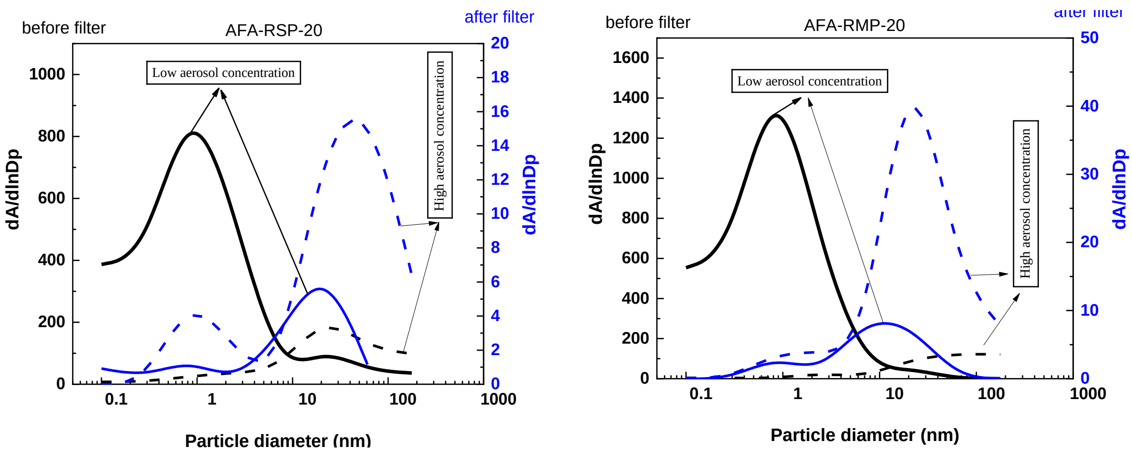


Figure 3. Activity size distributions with a wire screen diffusion battery, before and after RSP-20 and RMP-20 filters, at high and low aerosol concentration. Activity fraction in the Y-axis and the particle diameter in the X-axis is plotted. Before filter at left Y-axis and after filter at right Y-axis is.

It is clear from figure 3 that at high aerosol concentration 1 nm mode not exist. This is because the high attachment rate inside the radon chamber at high aerosol concentration. In this case, the 20 nm mode size is the essential observed mode measured with the wire screen diffusion battery with only 20 % of the total activity. The other activity fraction is transferred to the attached aerosol fraction with size more than 100 nm. Diffusion battery can't measure this size range. When the RSP-20 filter installed before the wire screen diffusion battery, nearly 90% of the collected activity with the 20 nm size mode is removed by the filter. The penetrated size is with several tens' nanometres. The obtained results indicate to the RSP-20 filter has a good filtration for the ultrafine size modes and the particles can penetrate that have size more than 20 nm.

RMP-20 filter similar to RSP-20 filter, it can remove 1 nm size mode. But the 20 nm size mode have a more penetration power than in the case of RSP-20 because the surface density of RMP-20 (3.5 ± 0.5 mg/cm^2) more than that of RMP-20 (3± 0.5 mg/cm^2). In this case, about 50 % of 20 nm particles penetrate the RMP-20 filter at low and high aerosol concentration. This present increases for old RMP-20 filters due to the electrostatic discharge according to the manufacturing.

Figure 4 presents the number size distribution of the ambient aerosol particles before and after RSP and RMP filters using holder set up as shown in figure 3. The number median diameter NMD of ambient indoor aerosol is less than 100 nm. RMP is two times more efficient to stop the aerosol particles than RSP filter. The penetration fraction of each filter with diameter is calculated and explained in figure 5. The 100 nm particles have 50 % penetration from RSP filter compared to 25 % for RMP filter.

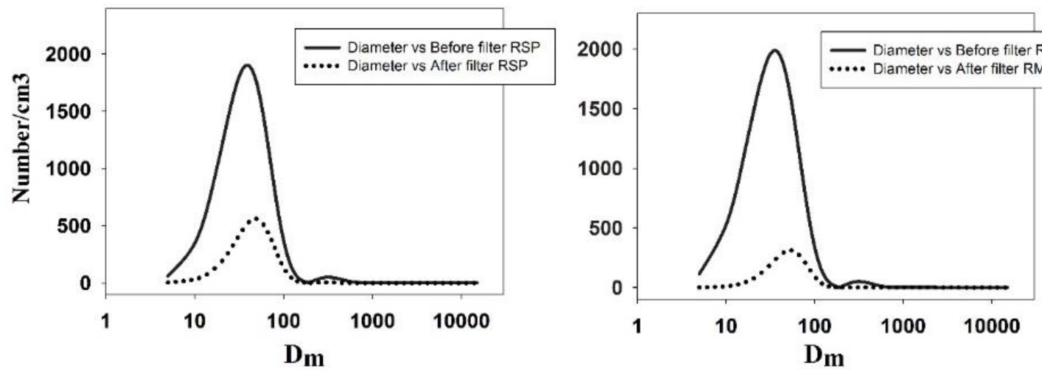


Figure 4. Number size distributions of the ambient aerosol particles before and after RSP and RMP filters.

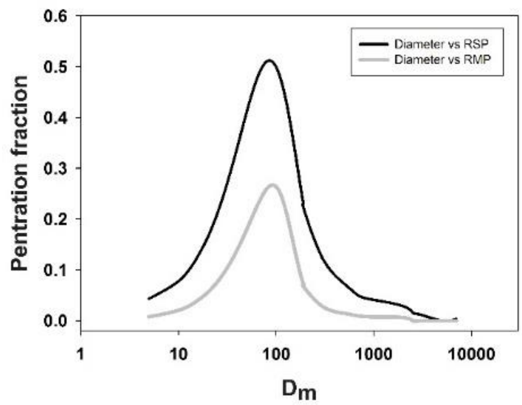


Figure 5. Penetration fraction of the ambient aerosol particles through the filters RSP and RMP.

Conclusion

- RSP-20 and RMP-20 radiometric analytical filters have a good filtration with low permeability for the ultrafine size modes (1-3 nm) of radioactive particles and the particles that can penetrate should have a size diameter more than 20 nm.
- The free unattached fraction of radon decay products completely stop with the analytical filters RSP-20 and RMP-20 which can be use as protected media.
- At high level of aerosol concentration, the RSP-20 filters more efficient and effective than RMP-20 filters to remove the radioactive particles with size diameter around 20 nm.
- For non-radioactive aerosol RMP filter more efficient than RSP filter.
- 50 % penetration for RSP-20 filter compared to 25 % for RMP-20 filter is observed for the particles of ambient indoor with NMD around 100 nm.

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